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ABSTRACT

The major results and conclusions of a program of research concerned primarily with the relationship of cognitive abilities to learning are summarized. The major purpose of this research was to develop theorems of instruction related to the interaction of task variables and individual difference variables and to develop them in a manner relevant to the instructional designer's task. The studies focused on the relationship of cognitive abilities to the learning of concepts and rules and to the learning of an imaginary science of "Xenograde systems." The goal was to establish a theoretical and methodological continuum from simple concept learning, through the learning of a complex system of concepts and rules, to a set of instructional design procedures which permit transfer of this knowledge into practice. On the basis of the studies a model for research in this area was recommended, cognitive processes relevant for concept and rule learning were defined, and a hypothesis construction model of simple concept learning was outlined, along with proposed theoretical considerations for more complex concept learning and specific recommendations for instructional design utilizing differences in intellectual abilities. (Author)

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RESEARCH PROGRAM ON COGNITIVE ABILITIES AND LEARNING

FINAL REPORT

1970

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The studies focus on the relationship of cognitive abilities to the learning of concepts and rules and to the learning of an "imaginary science of Xenograde systems." The goal was to establish a theoretical and methodological continuum from simple concept learning through the learning of a complex system of concepts and rules, to a set of instructional design procedures which permit transfer of this knowledge into practice. (U)

On the basis of the studies, a model for research in this area is recommended, cognitive processes relevant for concept and rule learning are defined, a hypothesis construction model of simple concept learning is outlined, along with proposed theoretical considerations for more complex concept learning, and specific recommendations for instructional design utilizing differences in intellectual abilities are made. (U)

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INTRODUCTION

The objectives of this program of research were summarized in the abstract of the initiating proposal, submitted October 12, 1967:

> The psychological investigation of human learning has been limited in at least two directions; first, the class of tasks studied has been too narrow and proscribed to permit ready generalization to educational settings; and second, behavioral psychologists have failed to integrate the data from the psychometric studies of individual differences in learning and thinking into their theories. Recent developments in cognitive psychology promise to narrow the gap between the study of learning and the study of individual differences. The new emphasis on individualized instruction in this country, along with the introduction of computer technology into the educational process, provides the opportunity to narrow the gap between the study of human learning in the laboratory and in practical training and educational problems.
>
> Questions of sequencing in a hierarchical task will be studied, using an imaginary science task which parallels the hierarchical structure of concept and rule learning in science and mathematics. A version of this task which employs an inductive or discovery approach will also be developed and investigated. The interaction of cognitive and other traits with different degrees of learner control and with expository versus inductive presentation will be explored. The interactions of cognitive abilities with treatment conditions in learning concepts and rules will be studied using laboratory concept tasks both on and off the computer as appropriate. This set of activities provides the link between learning theory and individual differences on the one hand and between instructional theory and instructional design on the other.

In the original proposal, stress was placed on the need that psychological research be relevant to the "state of the art" in instructional design. The instructional design model current then, developed and used by the Computer-Assisted Instruction (CAI) Laboratory for contract curriculum development funded by publishers, industry, and government, was described in the original proposal. This model represents a pragmatically oriented approach to instructional design and development, having the flavor of systems analysis. It permits quality control and management of curriculum development. The need to base the instructional designer's decisions on empirically validated, theoretical propositions rather than solely on the basis of intuition and trial and error was stressed. A long range goal of this research program (which was originally conceived to extend more than two years) was to develop those aspects of a theory of instruction related to the interaction between task variables and individual difference variables and to develop them in a manner relevant to the instructional designer's task.

A continuum was conceived for this program wherein the instructional design model marked the most applied extreme and represented the actual tasks an instructional designer had to perform, the approximate sequence of the tasks, and their interrelationships. This model was expected to evolve from research conducted on this project and on other more applied projects in the CAI Laboratory. The more basic end of the continuum was marked by the use of laboratory tasks familiar to the experimental psychologist. This allowed the research to be anchored at one end at least with relevant portions of the great body of data, methodology, and theory in human concept and rule learning, and limited forms of problem solving.

In an attempt to bridge applied instructional design activities and concept learning research, a CAI program was developed and evolved to teach "The Imaginary Science of Xenograde Systems. This learning task ties into the instructional design model by virtue of its design. It was designed using the steps and producing each of the products prescribed by the model. In particular, the task has a hierarchical structure wherein each node of the hierarchy is a performance objective as well as a concept or rule. Learning the rule could hopefully be related to findings in the more usual concept learning studies. The Xenograde task, however, also permitted empirical study of sequencing, individualizing techniques, and other problems known to be of primary concern to the instructional designer.

Research studies conducted under this contract thus can be classified under either the use of the Xenograde task or the use of more conventional laboratory tasks. A third category is the instructional design model, its evaluation, and the extent to which the research studies influenced it.

The purpose of this report is to summarize the research and other activities conducted under this contract and to evaluate the extent to which the strategy of bridging between applied and basic concerns was successful.

NOTE.--A summary of the research studies and other activities relevant to the objectives of this research program is found in Table 1. The table is broken into Categories I, II, and III, which represent (in the order of II, I, III) the continuum described above. These headings refer to: (I) research using the Xenograde task, and (II) instructional design and CAI. Category III summarizes concept research and other laboratory tasks. These three categories, with their roman numerals, also designate the three main divisions of this report. An evaluation chapter follows Section III.

S E C T I O N I

STUDIES RELATED TO THE USE OF THE XENOGRADE PROGRAM

Aptitude Interactions with Expository or Discovery Treatments

Contrary to over-optimistic hopes about the ease of conducting studies of human learning using a real-time CAI system, the problem of obtaining clean data was enormous. Loss of data due to program and hardware bugs, and proctor and operator error, are added to the problems of subject attrition and clerical error which plague the researcher. The complexity of program development and data analysis, using the early CAI languages and systems, sometimes added weeks to the time required to complete studies instead of facilitating data collection. These early problems made it necessary to repeat every Xenograde study at least once, except those of Merrill (1970) and Bunderson and Hansen (1971).

As programs and procedures became better and more familiar, these problems were reduced, and some of the early promise of CAI was realized. The use of the 1500 APL system greatly alleviated the programming and data collection problem so that at the end of the project, studies were sometimes run with great speed and rapid collection, sorting, and data analysis.

The first Xenograde study listed dealt with a simulated version of Xenograde in which students input parameter values of their own choosing and studied the resulting Xenograde display. This was the only early Xenograde study that was never replicated. Such learner-directed manipulation of the parameters of a simulation enables students to "discover" for themselves the relationships produced by the simulation model. The original pilot study made it clear, however, that simulation is inappropriate as a means of discovering concepts and rules for the first time in unfamiliar material, at least for subjects drawn from education courses. Simulation may be advantageous for integrating concepts and rules learned previously, testing in a more complex and life-like situation, demonstrating complex interactions, or generating example stimuli for expository instruction. The implications of this pilot study and other Xenograde studies were presented at a conference on computers in physics and mathematics education in August of 1970 (Bunderson, 1971).

Another problem with this initial simulation was its inordinately slow response time due to the clumsy calculation algorithm using fixed-point arithmetic in the counters of the Coursewriter II language. Further studies using simulation models to drive Xenograde displays were planned, and to this end, a floating-point arithmetic function (Smith et al., 1970) and a set of plot functions (Wheaton et al., 1970) for producing graphical displays on the cathode ray tube of the IBM 1500 system were developed. It was not possible to conduct such studies before the end of this contract, but the functions, in particular the algebraic function, have proved very valuable and have been disseminated among users of IBM 1500 equipment.

A series of four studies was conducted which examined the possible interactions of general reasoning, inductive reasoning, and associative memory with rule-example (ruleg or expository) vs. example only (discovery) instructional treatments. The first two studies were fraught with numerous problems and were considered pilot studies which led to important revisions in the Xenograde program and to hypotheses that were ultimately tested in later studies. The last two replications are reported in Technical Report No. 3. The first of these two pilot studies led to abandoning the group which used simulation with no rules or examples.

The second pilot study used the ruleg vs. example-only treatments, and it produced results which were quite influential, both directly and indirectly on later studies. In this study, 59 students from science education classes at The University of Texas at Austin participated, and 51 completed all cognitive tests and the Xenog program. The battery of cognitive tests was selected from the Kit of Reference Tests for Cognitive Factors (French, Ekstrom, & Price, 1963) and included two tests for each of the factors of Induction, Associative Memory, and General Reasoning. The Induction and Reasoning factors collapsed into one reasoning factor.

On the basis of this pilot work, several conclusions were reached. First, the discovery group required more examples to learn the science, but there were no differences between the groups on a posttest, a retention test, or a transfer test. Second, memory ability was found to be highly related to performance when statements of the rules were given, but this was not found when subjects were required to infer their own rules. This interaction was disordinal; i.e., the regression lines on memory for the two treatment groups crossed not far from the mean on memory score. In addition to these results, the pilot study also revealed that the amount of time required to learn the task was excessive and that several of the rules were too difficult. Consequently, the task was revised. A new task analysis procedure was used for the first time. The basic structure of the science was maintained, but several of the laws which governed the relationships of the system were changed. The verbal statements of the rules were simplified and the examples were selected so that only integer values, rather than decimal fractions, were shown. Hypotheses about the disordinal interactions with memory were generated which ultimately led to a study soon to be published (Bunderson & Hansen, 1971).

A second study was conducted to test the feasibility of the revised version of the Xenograde program. In this study, 80 subjects from science education classes at The University of Texas at Austin were run under the same design as described above. Unfortunately, usable data were obtained on only 30 subjects. The results of this effort are similar in several respects to the first pilot study. The discovery group again required a greater number of examples to learn the science. In this study, however, reasoning ability was found to interact with the treatments. The number of examples required by the discovery group was highly related, inversely, to reasoning ability. This was not the case with the group which was presented with statements of the rules. The inverse relationship between memory and performance in the discovery group, which was found in the study conducted before revision, was not replicated. Instead, memory was found to facilitate performance in the discovery group, as indicated by number of examples, rather than hinder it. This indicated that revision had somehow substantially altered the role of memory.

In the final study of this series, 53 students from science education classes at The University of Texas at Austin completed all factor tests, the Xenog program, and retention and transfer tests. This study was the same in all respects to the one just described, but it was regarded as a replication because of the small N in the previous study. The results were a replication of those in the previous study. The discovery group required a greater number of examples to learn the science, and the number of examples required was found to be highly related to reasoning ability. The positive relation of memory to performance was again observed. These results and their implications to instructional design were reported in papers presented at the annual meeting of the American Educational Research Association in Los Angeles (Bunderson, 1969a) and at the annual meeting of the American Psychological Association in Washington, D.C. (Bunderson, 1969b).

The curious reversal in regression slopes for memory before and after revision led to another study. This reversal occurred only in the discovery group. Before revision, the slope of the regression line was positive in this group, showing that subjects high on memory required more examples to learn (i.e., learned less efficiently). Following revision, the reverse was true: subjects high on memory required fewer examples to learn. Two variables which were changed in the course of revision were the availability of past instances (before revision, subjects could record previous instances on a worksheet) and complexity of the displays (irrelevant information was reduced during revision). Using the discovery treatment only, these two variables were manipulated in a 2 x 2 factorial design by reintroducing irrelevant information into the example displays to produce complexity and by manipulating availability through the presence or absence of a worksheet for recording examples.

This study perhaps comes closer to cross-validating results between the Xenograde task and the concept learning studies than any conducted during this program. The facilitative effects of memory aptitude on number of examples for learning the revised Xenograde task had its counterpart in number-of-trials for learning concepts in studies by Blaine, Dunham, and Pyle (1968) and Blaine and Dunham (1970). In a study by Wicklegren and Cohen (1962), however, subjects were allowed different sizes of "external memory," that is, notes they could write about previous instances. In this study, greater "external memory" led to poorer performances, corresponding to the positive regression of number of examples on memory found before revision in Xenograde, when a record of previous examples was kept.

This Xenograde study used 110 undergraduate education majors from The University of Texas at Austin. It was found that the reintroduction of availability did indeed reverse the slopes of the regression lines from negative to positive, both with and without complexity. The effect of complexity was not only to reduce the facilitating effect of associative memory (Ma) without availability for subjects high on Ma, but also to reduce the debilitating effect of Ma in the presence of availability of subjects high on Ma. There was no apparent effect of complexity on the performance of subjects low on Ma.

Disappointingly, these apparent disordinal interactions, produced by conscious manipulation of instructional variables, did not achieve statistical significance. A number of disordinal interactions of performance measures on Reasoning Ability were found to be statistically significant. However, these interactions had not been predicted. These results are reported in Bunderson and Hansen (1971).

The strong relationship of Reasoning Ability to Performance in learning Xenograde was the subject of the dissertation study by Merrill (1970). He hypothesized that the reasoning factors represented facility in certain information processing skills which enabled subjects high on this ability to focus more rapidly and accurately on the relevant aspects of example-only displays.

Previous Xenog studies in this series had shown that the introduction of rules reduced the apparent contribution of Reasoning Abilities to nothing. An instructional designer may still wish to use a discovery sequence, yet still desire to reduce the difficulty encountered by subjects low on Reasoning Ability. Merrill hypothesized that the presentation of performance objectives would introduce a focusing effect which would reduce the slope of the regression of performance on Reasoning Ability. In effect, the instructional variable would substitute an external focusing effect for the focusing generated by subjects high on Reasoning Ability.

Subjects were drawn from introductory educational psychology courses at The University of Texas at Austin, and a total of 131 completed all phases of the study. Both the availability of rules and of objectives were manipulated independently. It was found that objectives did significantly reduce the number of examples required to learn the task. This effect was not as strong as the facilitative effect of using rules. This significant reduction in number of examples was no stronger for subjects low in Reasoning than for those high on this ability. For test-item-latency, however, subjects low on Reasoning profited from the availability of objectives more than their brighter fellows did (who, it must be added, had less to gain).

Performance objectives are one of the most important products of the instructional designer's art. Merrill's study, taken as a whole, showed that as an instructional variable, objectives have orienting and organizing effects which dispose students to attend to, process, and structure relevant information in accordance with the given objectives. This facilitating effect is especially helpful to students lower on Reasoning Ability.

While aptitude x treatment interactions were the major concern of these studies, it is interesting to note what the results have to say about the discovery-learning hypothesis, vis., that learning by discovery leads to greater retention or transfer. Retention and transfer measures were taken in each Xenograde study. The transfer measure required subjects to infer several totally new rules, given new examples--a process presumably similar to the process they practiced during learning--but in no case was the discovery learning hypothesis supported. There was either no difference between the two groups or a difference in favor of the rule-example group. This was true even when the example-only group had the advantage of objectives to study. Contrary to most studies involving discovery learning, both groups were brought to the same criterion on the posttest by means of individualized branching in the CAI program. This resulted in more time and in the exposure to significantly more examples by the discovery group but no greater and, at times, inferior performance on retention and transfer. Students lower on reasoning and memory abilities had considerably more difficulty with the discovery treatment than with the expository presentation.

Those who favor the discovery hypothesis may argue with our operational definition of discovery or with the perhaps unusual motivational aspects of the Xenograde task. This may not correspond to their definition of discovery. Until someone is able to define better what is meant by discovery and to locate the source of any supposed advantage, the instructional designer must be wary of abandoning the powerfully-effective tool of well designed rule-example presentations, especially if he is dealing with populations heavy on the lower ends of the ability scales used in these studies.

Another approach to one aspect of what might be meant by discovery learning is through investigation of learner control vs. program control of instructional sequence and other variables. Two Xenograde studies were conducted to investigate the effects of mainpulating the sequence of rules in the Xenograde learning hierarchy. In both of these studies, only the rule-example version of the program was used. In the first study, the subjects were 118 students from introductory educational psychology courses at The University of Texas at Austin. Since only 49 completed the first one, it could be regarded only as a pilot study. It was replicated with minor modification, using 176 students from introductory educational psychology courses, 152 of whom completed the study.

The basic rule-example treatment was augmented by a representation of the hierarchy of rules which constituted the Xenograde science. Using this hierarchy as the basis for defining alternate sequences, an index of sequence was defined, as follows: The index was 1.0 when the sequence was in the perfect hierarchical order (that is, from the lowest order rule to the highest). The index was .5 when an essentially random sequence of rules was taken; and the index was 0.0 when the reverse sequence (top to bottom of the hierarchy) was taken. While there are several variations among treatment groups used in this study, only two basic variations are reported here. One group was assigned to different sequence conditions from 0.0 to 1.0 and were led through sequences by the CAI program. Another group was shown the representation of the hierarchy, and each student was allowed to choose his own sequence.

The principal findings were that (except for the 0.0 sequence) students in the learner-control groups did better when they chose an idiosyncratic sequence than when they chose the 1.0 sequence. Motivational effects were postulated to be at the root of this finding. On the other hand, students assigned randomly to different sequences did poorly when the sequence was scrambled and did progressively better as the sequence approached an index of 1.0, where they did significantly better than students who chose a sequence of 1.0.

It was found that the inductive reasoning factor was highly related to success in the forced group when the sequence was scrambled but was not related when it approached 1.0.

Mean posttest score for students under program control was significantly better than for learner control, despite negative sequence effects.

S E C T I O N   I I

INSTRUCTIONAL DESIGN AND CAI IMPLICATIONS

The activities in this section, as indicated in Table 1, relate to computer-assisted instruction more generally as well as to instructional desig Previously mentioned were the technical reports listed in the table under II.B, which document special-purpose author language functions. These expanded considerably the answer processing, display, and simulation capabilities of the IBM 1500 system.

The papers listed under A in Table 2 are primarily concerned with various aspects of instructional design or of the implications of aptitude x treatment research findings to instructional design.

The instructional design model provides a conceptual structure for classifying the products of instructional design in a manner highly related to the production of documentation products as well as final program materials. The intermediate and final products of instructional design are outlined in an organized scheme and are discussed by Bunderson (1970a, 1971).

Technical Report No. 2 is a "case study" of instructional design and documentation and is the manual for the Xenograde program, written to reveal the various design products prescribed by the model. The manual is slanted toward a supposed audience of researchers rather than potential educational users due to the nature of the Xenograde program. This second report thus attempts to convey some of the rationale behind linking instructional research to carefully rationalized and carefully documented instructional design of an experimental task, as well as demonstrate how such a procedure might aid in accomplishing the linkage of research to relevance--of science to engineering.

The papers presented at the annual meetings of the American Educational Research Association and the American Psychological Association (Bunderson, 1969a, 1969b, 1970b) concerned the relevance of aptitude x treatment interactions to instructional design. In these papers, an increasing tone of skepticism was expressed toward the practical value of disordinal interactions between treatments and aptitudes.

The methodological model for our research during the course of this project came to resemble that discussed by Cronbach and Snow (1969). Given two or more separate instructional treatments, the argument goes, it may be possible to find one or more aptitudes (broadly defined) which will interact such that students low on the measure of an aptitude may do significantly better in one of the groups than in the others, while for students high on that aptitude, the reverse may be the case. This interaction is observed by a regression analysis wherein the regression lines of performance on aptitude, calculated separately for each treatment, cross well within the range of the aptitude measure. Such a pattern of regression lines is termed a disordinal interaction.

Methodologically, this approach has much to be commended in research studies. It is assumed by Cronbach and Snow, however, that results of this sort can lead in a natural manner to improvements in instruction by assigning individuals to different treatments based on their aptitude scores. It is this assumption that is challenged in the three papers cited above.

Four interrelated reasons were given for this skepticism:

(1) *The rarity of useful disordinal interactions.* It is more common to find no interaction than otherwise. When interactions are found, they are more likely to be ordinal interactions (regression lines cross outside the range of the aptitude measures) than disordinal. When they are found to be disordinal, they often prove to be of no value relative to alternate assignment since the point of intersection of the regression lines follows so closely to an end of the aptitude range as to provide no hope for practical instructional advantage.

(2) *Disordinal interactions may not be sufficiently robust under even seemingly minor changes in the task or population.* Revision of a task is the instructional designer's most powerful tool. As the Bunderson and Hansen (1971) study indicates, revision may produce regression results partially predictable on the basis of an understanding of the variables being manipulated, but these modifications may produce quite unexpected and possibly more important interactions with other aptitudes.

(3) *Ceiling effect on the methodology of regression analysis.* Successful instructional design enables all subjects to reach a high performance criterion. By design, there is almost no variance in posttest scores (for example), allowing the variance to reappear in the number of examples seen or in the amount of time taken. Treatments in which there is sufficient variance remaining in posttest scores to seek disordinal interactions may be in need of substantial revision, which introduces the robustness problem (described above) and which produces, if successful, a situation where regression analyses cannot be applied, at least not on the posttest score.

(4) *Payoff relative to further instructional design and revision.* The payoff attainable through alternate treatment assignment based on a disordinal interaction may be less than that attainable through revision of the single best treatment. In instructional design, there is probably no factor that produces more improvement for more students than the careful revision of a program based on detailed feedback of student responses, attitudes, and response times about specific details of an instructional program.

It was proposed in the APA presentation by Bunderson (1970) that, at least for the class of tasks and aptitudes studied in this project, a more fruitful approach would be to look at single-step regression lines rather than to seek disordinal interactions. If a strong regression exists, the instructional designer can ask himself why. He can introduce changes in the program to reduce that information-processing burden for the low-aptitude individuals. Hopefully, using the information-processing constructs developed through the rationale described in Section III, he can select--based on theory--instructional variables to manipulate during revision. The variables he introduces, in a CAI program at least, might be "micro-treatment" variables applied adaptively within a branching CAI program rather than through the production of an entire alternate treatment (Bunderson, 1969b).

It was also suggested that the micro-treatment methodology and the analysis of regression patterns for single treatments lead more naturally to an optimization methodology than to the methodology of regression analysis and macro-treatments described above. In this approach, aptitude measures become parameters in optimization models of some type (which can be applied dynamically within CAI programs). This thinking found more powerful expression in the laboratory research studies, which are summarized in Section III.

The formulation of new information-processing constructs relevant to both aptitude tests and concept-learning tasks discussed below is seen as providing the constructs and construct-validation methodologies permitting the development of mathematical hypothesis-construction models of concept learning. If this evolving approach is successful, it may prove to have the strengths of the optimization approach described by Atkinson (1970) for instructional decision-making and learning theory. Hopefully, it might also contribute some of the conceptual richness characteristic of the Guilford aptitudes tradition from which this project is an intellectual descendant.

It should be recognized in evaluating the findings of this research project that we have restricted the investigation almost exclusively to cognitive aptitudes and to concept and rule-learning tasks. The subject's learning process for these tasks occurs over a relatively short period of time. Cronbach and Snow (1969) stress that disordinal interactions should be sought in learning situations which occur over a longer period of time so that subjects can become attuned to the instructional treatments. Under long-term learning situations and by using noncognitive as well as cognitive aptitudes, it may be possible to justify the design of two or more macro-treatments and to assign individuals to alternate treatments for instructional gain. A task for the future is to apply the methodological approach and conceptual models developed in this project to longer term learning to determine whether or not it might have the same advantages found here.

The paper by Merrill (1971) was written after he received the doctor of philosophy degree and had accepted a position at Florida State University. The algorithmic or information-processing analysis procedure which he describes was conceived during the series of Xenograde studies, however, and is described in preliminary form in Olivier (1970) and Merrill

(1970). The information-processing analysis approach Merrill describes has its counterpart in the methodology described in the following section for laboratory tasks. Merrill's paper is included in this report to complete an important conceptual symmetry between the parts of this project represented in Table 1.

A few words must be said about the importance of the instructional design model (which substantially evolved during the course of this project) to developments of national significance in CAI. The paper entitled "Computer in Mainline Instruction" (Bunderson, 1970a) laid the foundation for an approach to the introduction of cost-effective CAI into junior colleges and other adult education institutions. This approach has found expression in major proposals to the National Science Foundation (NSF) submitted cooperatively by MITRE Corporation and The University of Texas CAI Laboratory. These proposals aim toward the development and introduction of low-cost, market-oriented systems consisting of a marriage of television and computer technology on the hardware side and of curricula designed according to the instructional design model on the educational side. An extension of the learner-control research and the instructional-design research initiated in this project has found continuing support through a five-year grant from the National Science Foundation for research in instructional design and authoring systems (Grant GJ 509 X, initiated June, 1968).

SECTION III

STUDIES RELATED TO THE USE OF LABORATORY TASKS

A cursory glance at the list of studies appearing under the heading labeled III in Table 1 representative of the larger portion of effort in this project does not convey the evolutionary logic and interrelationships which existed among these seemingly diverse activities. The studies fall into clusters, indicated by the subheadings of A through E, with Category F representing extensions of the basic methodology beyond concept-learning tasks and cognitive aptitudes. This section begins with a general overview of all studies listed under the heading labeled III in Table 1. Subheadings for Categories A through F then designate detailed reports and interpretations of the various studies.

The fundamental ideas on which the series of studies was based are as follows (hereinafter designated as Propositions 1, 2, and 3):

(1) The most critical step in understanding and predicting complex learning behavior comes through a careful and accurate analysis of efficient human information-processing strategies for that class of tasks.

(2) Cognitive aptitudes relevant to performance on a class of tasks may be selected, and their interactions with treatments may be understood in relation to their relevance to the information-processing requirements of the task.

(3) Experimental manipulations of task variables produce effects on task performance and on aptitude interactions understandable from the manner and extent to which these manipulations alter the information-processing requirements of the task.

The clusters of studies designated A through F under III in Table 1 can be placed in context to the extent that they elucidated one or more of the Propositions 1, 2, or 3 in relation to concept-learning tasks and corresponding cognitive aptitudes.

Clusters A, B, and C were concerned with multiple-category conjunctive concept problems. Such problems are characterized by the learning of a multiple response system to the values or combinations of values on the relevant dimensions. Prior analysis of this problem had led to the definition of two decision rules which could form the basis for efficient information processing strategies in solving these concept problems. Studies in Category B were concerned with the effect on task performance and aptitude interactions of manipulating an instructional variable, namely, information about and practice on one or both of the decision rules. They relate most clearly to Proposition 3, and established the modest but important conclusion that experimental manipulations which produce no mean differences may nonetheless produce important differences in aptitude patterns.

The second of these studies set out to accomplish more than the statement implies by separating the stages of learning in the multiple-category task and providing instruction on the two decision rules separately for different groups. Based on this detailed analysis of the task, predictions were made relative to aptitude interactions. The complexity of the results indicated that further definition of both the information processing occurring in different instructional treatments and of the aptitudes was necessary. Recognition of this difficulty was influential in leading to the methodological innovations of the studies in Category D and the theoretical considerations of Category E.

The final study in this series was not an aptitude-treatment interaction study. It relates to Propositions 1 and 3 and reflects a considerably advanced understanding of the interaction between the strategy (decision rules) used by learners and the sequence of concept exemplars. The role of contiguity in concept identification, contrary to previous literature, was shown to be dependent on the learner strategy. While it was not possible to follow up the implications of this study to the more instruction-oriented aspects of this program, the implications may be worthy of serious investigation. The careful shaping of the structure and sequence of concept exemplars based on theoretical propositions derived from basic research and applied to information-processing analyses of complex school learning tasks may become a powerful instructional design technique (e.g., Tennyson, Wooley, & Merrill, 1970).

The study in Category C further established the conclusion that aptitude interactions may exist in spite of a lack of mean differences between treatment groups (Blaine & Dunham, 1970). This study (Blaine & Dunham, 1971) showed also that the relationship of memory to performance could be manipulated by varying the availability of previous instances, although, as in the second study under Category B, the relationships are not easily interpretable. This study relates to both Propositions 2 and 3 and to the Xenograde study discussed above (Bunderson & Hansen, 1971).

The series of studies in Category A of III in Table 1 relates most directly to Proposition 1 and that part of Proposition 3 concerned with task performance rather than aptitude interactions. Prior experimental work and analysis of the multiple-category concept problem had led to the suggestion that there may be two steps involved in the solution process (Overstreet & Dunham, 1969). These two stages were designated as dimension selection and associative learning. In order to study the effects of task manipulation on the two decision rules necessary to efficient performance in problems of this type, it is necessary to separate experimentally the dimension selection and associative learning stages. This was done with increasing sophistication in understanding of and control over the students' use of these decision rules through the series of studies designed under Category A. In Overstreet's dissertation (1970) the implications to mathematical models, such as that of Chumbley (1970), and to the model developed as a result of the research in Category E were drawn.

Although not employing aptitude measures, these studies were important both methodologically and conceptually to the evaluation of thinking about the aptitude treatment interaction problem. The methodological separation of the dimension selection and the associative learning stages was attempted in the second study in Category A. The refinement of thinking about the information processes involved in concept learning were fundamental to certain of the methodological innovations in the studies in Category D and were helpful toward the representation of important information-processing constructs in mathematical model form (Category E).

Activities listed under Category D came to represent the most important conceptual and methodological contribution of this project to research and theory involving aptitude x treatment methodology. Using the increased sophisitication in information-processing analysis of concept-learning tasks, studies in this series produced a variety of new measuring instruments for both cognitive abilities and concept-learning problems, including non-specified dimension problems as well as the multiple-category problem. Assuming that variance in performance on both relevant conventional ability tests and concept learning tasks could be accounted for by the same set of processing constructs, studies in this series set out positively to define these constructs through a new methodological procedure and to use them powerfully in studies which integrate all three of the propositions listed above. Because of the importance of these concepts, extra space is given to them in this report.

Studies of this type can yield information-processing constructs which account for large portions of variance in complex concept-learning problems, and possess construct validity relative to important stages and decision strategies in concept learning. Such constructs and their operational linkages to data are prerequisite to the development of mathematical models of complex concept-learning behavior. The studies listed under Category E do not yet relate to Proposition 2, but they are in the mainstream of thinking on this project. This is so because they lead toward the incorporation of the information-processing constructs developed in the project at large in hypothesis-construction models of concept learning. Such models will require the addition of parameters to represent the aptitude process constructs shown to interact importantly with alternate treatments.

The two dissertation studies listed under Category F extended the process-analysis aptitude treatment methodology of this project in two new directions. Most ambitious was the study by Hollen (1970), who attempted an information-processing analysis of learning from connected discourse. The position of adjunct questions was the task variable predicted to produce aptitude interactions with different memory abilities. Hollen attempted to develop a new process test for a hypothesized memory process and for predicted changes in the regression of performance scores on two memory abilities due to the influence of adjunct questions on processing requirements. As was the case in most of our early Xenograde and concept studies, the results were not wholly consistent with the predictions nor were they easy to interpret. The aptitude x treatment interaction problem in a new task domain seems tractable only through a difficult sequence of iterations between detailed task analysis, construct validation, and empirical observation.

The dissertation by Meyers (1971) built on the foundation of research laid here on the multiple-category concept problem and examined the effect of anxiety, moderated by ego involvement, on cognitive aptitude x treatment interactions.

Multiple-Category Conjunctive Concept Problems

Multiple-category conjunctive concept problems are characterized by the learning of a multiple-response system to the values or combinations of values on the relevant dimensions. Prior experimental work and analysis of this type of concept problem has led to the suggestion that there may be two stages involved in the solution process (Overstreet & Dunham, 1969). First, the subject must determine the relevant dimension or dimensions of the problem. Once the relevant dimensions have been determined, the subject must learn the responses which are associated with the different values displayed by the relevant dimensions. This interpretation suggests that different abilities might be related to the respective stages of the task. Further, treatment manipulations may affect the relationship of abilities to performance only in terms of one stage of the solution process.

Experiments were conducted to investigate the "stages of learning" interpretation of multiple-category problems (Overstreet & Dunham, 1970; Overstreet, 1970). These experiments employed multiple-category problems which were experimentally separated into the dimension-selection and response-learning stages. It was possible to specify two decision rules which subjects could use in determining the appropriate dimensions. Both rules necessitated a comparison of two instances and differed according to whether the comparison instances were from the same or different response categories.

In one study, subjects were instructed on one of the two rules and then received problems varying in the number of irrelevant dimensions and the number of values per dimension. Subjects were forced to solve the dimension selection phase by using rules for which they had been instructed. One of the rules allows only the elimination of pairwise combinations of dimensions but not the elimination of any single dimension. The other rule permits the elimination of a given dimension without regard to any pairwise combination it has with any other dimension. Thus, an interaction was predicted between rule-type and number of irrelevant dimensions in the dimension selection phase. On the other hand, neither of these variables should affect the response learning stage, while the number of values per dimension should have a great effect on response learning performance. This outcome was predicted since the number of responses the subject must learn increases as the number of values per dimension increases.

A total of 137 subjects from introductory psychology classes were run individually. The concept materials were presented at the cathode ray tubes connected to the IBM 1500 system. The results supported the hypotheses, indicating not only that stimulus complexity variables differentially affect performance within the different stages, but also differentially affect the efficient execution of information processing strategies.

Procedural problems in Experiment I made it possible for subjects to reduce one information-processing rule to an artifactually simpler form. Experiment II, utilizing a modified procedure, was undertaken to replicate the previously-obtained differential difficulty of the information-processing rules and to clarify the interaction of rule-type and number of irrelevant dimensions. Each subject solved two problems without associative learning.

The results of this second experiment replicated the basic relation between type of rule and difficulty which had been obtained in Experiment I. The number of dimensions by rule-type interaction obtained in Experiment I was not replicated in the second study, suggesting that a significant proportion of the subjects in the across-category rule conditions in Experiment I may have discovered and utilized the simplified form of this rule. No main effect for number of irrelevant dimensions was obtained in this second experiment.

The results of these studies were interpreted as casting doubt on the appropriateness of the sampling-process assumptions underlying current hypothesis-testing models of multiple-category concept attainment. Specifically, the results were interpreted as suggesting that a subject who is faced with an error that infirms his hypothesis may be able to compare that hypothesis with the currently available stimulus and its feedback to derive information which would allow him to restrict temporarily the pool of dimension pairs from which he will sample.

The implications of this restricted sampling assumption, in two forms, were investigated with regard to the Chumbley (1970) model of multiple-category concept attainment. A further differentiation of Chumbley's aptitude interaction state into two states corresponding to (1) hypotheses containing only irrelevant dimensions and (2) hypotheses containing one relevant dimension was suggested to account for the results of these studies.

Decision Rules and Concept Learning

In addition to the investigation of the nature of the multiple-category problems, several studies were conducted in which the concern was the relationship of cognitive abilities to performance on such tasks under differing treatment conditions. One study (Dunham & Bunderson, 1969) was undertaken to determine the effect of instruction on the dimension selection rules described above and the relationship of cognitive abilities to concept-learning performance. One hundred thirty-six students from an Austin, Texas, high school were randomly assigned to two groups. A total of 69 subjects received instruction on the use of the dimension selection rules. The remaining 67 subjects received instructions on the nature of the concept problem but were not given the additional rule instruction. All were then given a series of multiple-category concept problems.

There were no differences in mean performance across problems for the two groups. However, the introduction of rule instruction did alter the role of the abilities in the solution of the concept problems. The performance of the group given rule instruction was highly related to a reasoning ability while the performance of the group without rule instruction was highly related to an associative memory ability. Thus, students with a particular cognitive ability profile were successful under one condition, while those with a different profile were successful under the other condition.

In the above study, it could not be determined whether the lack of mean differences was due to the inapplicability of the rules or to inadequate instruction on the rules. Consequently, a pilot study was conducted to determine whether or not training subjects to use the rules would facilitate performance in a subsequent multiple-category problem. A group of 33 subjects received instruction on the use of the rules and were then presented with a series of training problems. Following this, the subjects were given a four-category conjunctive concept problem. A second group of 32 subjects did not receive the instruction and training on the use of the rules but received the same four-category problem as the training group. The results of the study indicate that training on the rules does facilitate subsequent concept performance.

In the first aptitude x treatment interaction concept study, two decision rules were involved in the rule instruction. Since this was the case, an additional study (Dunham, 1969) was undertaken to determine if the use of one of the rules would require different abilities than those required by the other. The subjects were 68 undergraduates from introductory educational psychology classes at The University of Texas at Austin. Instruction and training on the dimension selection rule involving a comparison of two instances from the same category were given to 37 subjects. The remaining 31 were given the same instruction and training with the exception that it was with the rule involving a comparison of two instances from different categories. The training for both groups involved specially-constructed problems which could only be solved using the rule for which the group was instructed. Following the training phase, the subjects were given the same multiple-category concept problem.

The results indicate that the rule involving a comparison of two instances from the same category is the easier of the two rules when subjects were forced to use a particular rule. There were no differences in mean performance in the subsequent concept problem. However, there were differences in the relationship of abilities to performance on this problem for the two groups. Performance in the condition with instruction on comparison of instances from the same category was substantially related to a reasoning ability, while performance in the other condition was most highly related to an associative memory ability. Thus, the use of the two decision rules were related to different abilities.

In both of these studies, instruction and/or training on decision rules relevant to attaining solution in multiple-category concept problems did not effect differences in mean performance but did affect the relationship of performance to cognitive abilities. The treatments in these cases probably changed the information-processing requirements in the task as reflected by the differential correlations of the dependent variable with the ability measures. This would imply that different people, as represented by different ability profiles, would succeed under the different treatments. Such differences, however, could balance out and not be detected if only the means were examined.

Availability of Instances and Memory

An additional study (Blaine & Dunham, 1969) was executed involving the same underlying theme as the above studies. It has consistently been shown that providing subjects with available past instances facilitates performance in concept-learning problems. This effect is usually interpreted as due to a reduction in the memory requirement of the task. If this is the case, the introduction of available past instances should effect a reduction in the relationship between tests of short-term memory abilities and performance in a concept-learning problem.

The subjects in this study were 60 undergraduates from introductory educational psychology classes at The University of Texas at Austin. A battery of tests of short-term memory abilities was selected from Guilford's Structure-of-Intellect model (Guilford, 1967). The subjects were then presented with a multiple-category concept problem, 30 of whom were given the problem by the regular method of anticipation, while the remaining 30 were presented the same problem but such that the just previous instance and its feedback were always available.

There were no differences in the mean performance of the two groups. This result appears to be inconsistent with previous research. However, the number of available instances employed in this study was at a minimum, the smallest number ever used in such investigations. Although there was no difference in performance between the groups, the relationship between the short-term memory was substantially correlated with performance. Within the group with a past instance available, the relationship was reduced. In fact, only one test retained a positive relationship with performance. This test has been shown to be related to "cognition" ability while all other tests have consistently been related only to "memory" ability. Thus the results of this study support the contention that making past instances available reduces the memory requirement of the concept task. In addition, the results are consistent with the previous studies in that an experimental treatment which does not effect differences in mean performance can alter the role of cognitive abilities in task performance. Such a result is made manifest only by an examination of the covariability of the dependent variable with measures of cognitive ability.

Process Measures for Aptitude and Learning

Given the limited amount of research that has been conducted, it may not be possible to present a general, integrated approach to the research question concerning the role of individual differences in concept learning. What is possible and necessary is to realize some of the problems involved in research of this type and to consider different avenues of investigation.

It appears that an appropriate place to begin any investigation of the relationships between abilities and concept learning would be an analysis of the task in terms of the processes that the learner must execute in order to attain solution. This would provide not only an understanding of the task itself, but also a basis for determining the ability requirements of the task. If the investigator is able to specify what processes must be executed, he should know what abilities would be relevant to performance in a learning task. He can then design treatment options which are most likely to be instructionally effective or psychologically interesting, depending on his objectives.

Therefore, analyzing the task in terms of the processes required of subjects to attain solution of the concept-learning problems should provide a better understanding of the ability requirements of the task. One study (Blaine, 1961) was designed and executed using a sample of 200 students from an Austin, Texas, high school. For this study, a number of new tests were developed in which the items were intended to require the subjects to execute a process which would be required in the multiple-category problems that the subjects had to solve. An attempt was made, on the basis of the analysis of a multiple-category problem, to develop tests which separately assessed all the processes required for solution of the concept problems.

The experimental materials were administered in three-hour blocks on each of three consecutive days. The first day's materials consisted of a battery of known ability tests which are frequently used in testing for individual differences in learning research. On the second day, the subjects were given eight multiple-category concept learning problems in which measure of both dimension selection and response learning were obtained. The specially-developed tests were administered during the third day's session.

The known tests of abilities and the specially-developed tests have also been administered to a sample of undergraduate college students from introductory educational psychology classes at The University of Texas at Austin. The two batteries of tests were administered in two separate sessions.

It was assumed that the data from these studies would provide information which is highly relevant in considering individual differences in learning. The relationship of the tests constructed to assess execution of required processes to performance in the concept problems provides an evaluation of the analysis of the solution process in multiple-category concept problems: It was also assumed that the interrelations of these tests with the known ability tests would indicate the extent to which the known ability tests assess the execution of processes required by a specific concept task.

The process tests predicted performance on the concept problems as well as the aptitude tests. More importantly, the execution of this study underscored several problems which have given rise to the consideration of an alternative approach to the study of the relationships between cognitive abilities and performance on concept learning problems.

Knowing what abilities are relevant does not necessarily imply that they can be adequately assessed. If, after analyzing the task several abilities are shown to be relevant, the investigator is still faced with the problem of assessing an individual subject's capacity to execute the relevant processes. After this is accomplished, there is no guarantee that the tests of known cognitive abilities will be related to the specific concept-learning task. Absence of this relationship may be the case if differences exist in content between the task and the test or in the level at which the ability is assessed. This reasoning could lead to the extreme of having a unique set of tests for every possible learning task, which does not appear to be feasible or appropriate.

It seems it is necessary to clarify the term "relationship" as it is used in the phrase "the relationship between abilities and concept learning." Traditionally, it has been interpreted to mean that the ability, as measured by tests of known abilities, was necessary in solving concept-learning problems. If, for example, Ability A has a lesser relationship to a concept-learning problem than Ability B, it would imply that Ability B is utilized more than Ability A in solving the task. This kind of interpretation implies that known tests of abilities measure single, specifiable cognitive processes or that several tests of the same ability measure the same single, specifiable cognitive process. The results of these two studies showed that this is not the case. Most tests commonly used to define an ability factor contain several specifiable cognitive processes. This indicates that the relationship between abilities and performance on a learning task may partially, be a function of the similarity of the cognitive processes employed to attain solution of a concept-learning problem and to perform adequately on an ability measure. Allison (1960) interpreted the common factors in measures of learning and of aptitude and achievement as being dependent upon the similarity of the psychological processes and the contents of the material involved in the various learning tasks or references variables.

Traditionally, studies of abilities and learning have attempted to establish direct relationships between these two domains by utilizing various factor-analytical techniques. This approach has the disadvantage of, in many cases, not establishing clearly the relationship between abilities and learning. An alternative approach to this is to posit the existence of a third domain: processes common to both learning and abilities. Psychologically, it may be possible to conceive of the ability tests as being a composit of small concept learning tasks. This is true of Induction and General Reasoning tests, and it may also be the case, in general, for tests of known cognitive abilities.

The major difference between tests of abilities and concept-learning tasks appears to concern the feedback mechanism. In concept-learning tasks, feedback is usually supplied, whereas in ability tests, the feedback mechanism is generated by the subject. If,then, ability tests and concept-learning tasks are both similar forms of learning tasks, it would seem appropriate to examine their relationship by examining the processes common to both.

If a process domain could be established, it is hypothesized that it would consist of several relevant cognitive processes that would be similar to those the subject must execute in performance on both concept-learning tasks and ability tests. The advantages of working with process measures would be: (1) to reduce the entire single domain of ability measures to a relatively small number of cognitive process measures, and (2) that after having established this, to construct models of a mathematical nature that would incorporate structures similar to those of cognitive processes. If this were done, it would allow the investigator to examine the role of individual difference parameters in concept learning.

A general outline is proposed to explain how a domain of cognitive processes might be constructed, and the cognitive ability of Induction is used as an example. If several measures of Induction were examined with respect to the processes the subject must perform to attain an adequate score on the ability measure, several specifiable cognitive processes could be isolated. Different measures of these processes could then be constructed. These measures would be constructed such that they would be as similar as possible to the original ability measure; that is, they would be specific to the processes relevant to that original ability test and would contain the same content material.

In constructing such measures, they would be univocal with respect to the cognitive processes necessary for performance on the ability test. If this same type of analysis were undertaken with respect to the concept-learning task to be used, measures of processes relevant to the concept-learning task could also be constructed. If these new measures were then factor-analyzed, the resulting factor structure would be an indication of the process common to the Induction ability and the concept-learning task. If this same type of procedure were carried out with respect to a wide range of ability measures and concept-learning tasks, it would then be possible to establish a domain of cognitive processes that are common to both abilities and concept-learning tasks. This procedure is depicted schematically in Figure 1. Note that the transitions from the known ability tests to univocal ability process tests are rational. An analytic process must be employed by the perceptive and experienced experimenter. The same is true in obtaining the univocal process measures from the learning tasks. Here, one is assisted by empirical confirmation, such as the series of studies previously described related to the analysis of multiple-category problems in different stages. Experimental manipulation of variables effecting hypothesized information processing by subjects is a powerful technique to aid the search for construct validity.

While obtaining univocal process measures, primarily by rational analysis, one is assisted in his search for process constructs common to both domains by the technique of factor analysis. Dimensions thus obtained can be used in experimental studies in the same way that conventional aptitude measures are now used but with greater expectation of interpretation and generalizeable results.

Pursuant with the logic in Figure 1, studies were undertaken to examine the relationship between abilities and performance on concept-learning tasks in terms of the similar cognitive processes involved (Costello & Dunham, 1971; Costello, 1971). When multiple treatment groups are employed instead of a single treatment group, the relationship between an ability and performance within any treatment condition may be considered a function of an increase or decrease by treatment manipulation in the similarity between cognitive processes measured by that ability and those cognitive processes necessary to solve the concept tasks. In essence, a treatment manipulation defines what processes relevant to solution of the concept tasks in that condition are involved. Given the restraings imposed by the treatment manipulation, the relationship between abilities and performance is a reflection of how well ability tests measure cognitive processes similar to those involved in concept learning.

This analysis of the relationship between abilities and performance on concept-learning tasks is especially useful with abilities that show strong relationships to performance under several different treatment conditions. If an ability relates strongly to performance across several treatment groups, it does not necessarily imply that the relationship is the same. The ability of induction, for example, has been shown by Dunham and Bunderson (1969) to have emerged as a general factor and to contribute strongly to performance under two different conditions. Traditionally, this would be interpreted as an implication that induction is important to concept learning. If concept-learning studies are considered to be concerned with the individual's induction of the rules of belonging and not belonging, it is not surprising then to find that induction has a strong relationship to performance under different conditions. To say that induction and concept-learning are highly related provides no further information about their relationship. It

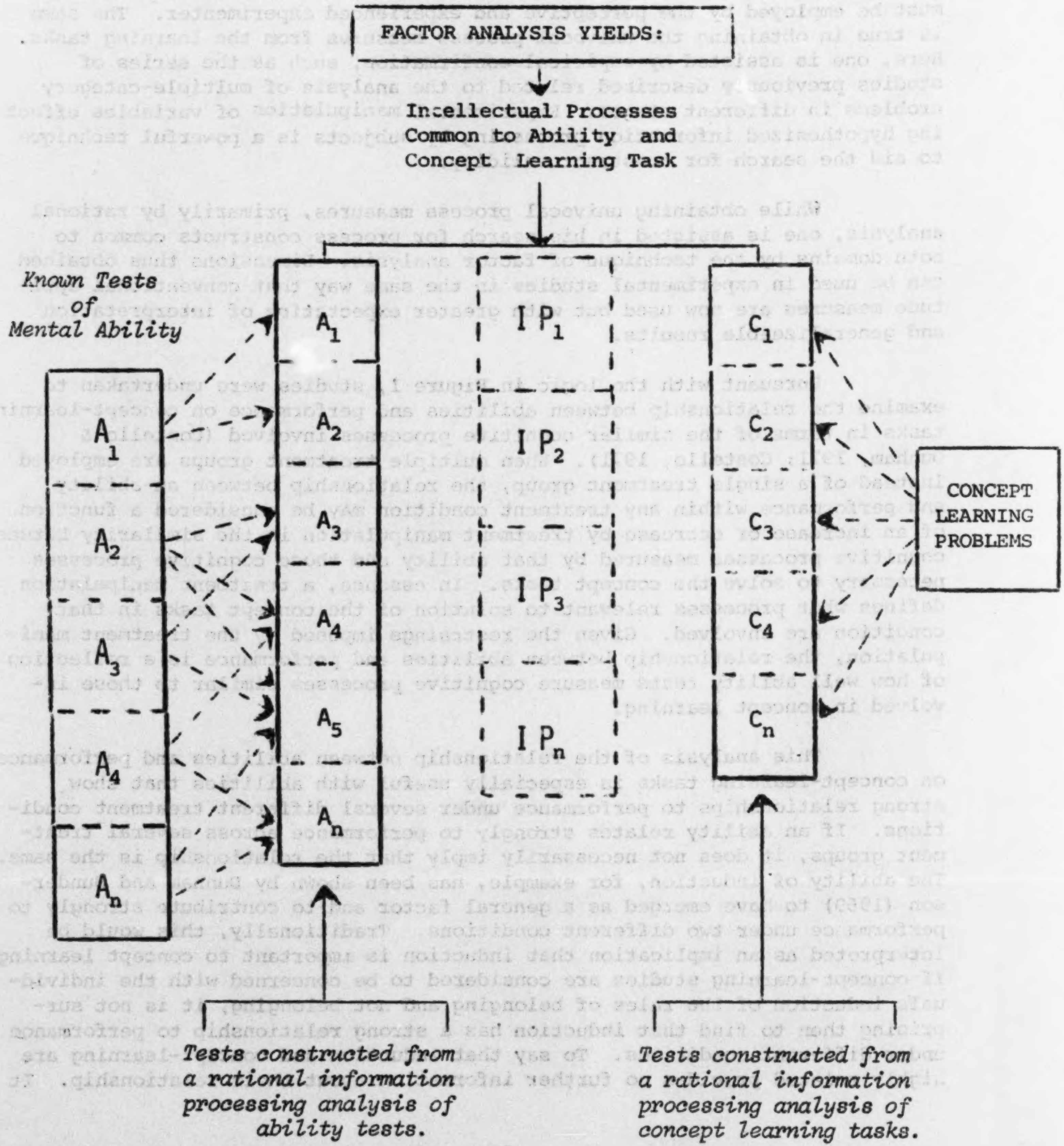
FACTOR ANALYSIS YIELDS:
Intellectual Processes Common to Ability and Concept Learning Task
Known Tests of Mental Ability
A1
A2
A3
A4
An
A1
A2
A3
A4
A5
An
I P1
I P2
I P3
I Pn
C1
C2
C3
C4
Cn
CONCEPT LEARNING PROBLEMS
Tests constructed from a rational information processing analysis of ability tests.
Tests constructed from a rational information processing analysis of concept learning tasks.

Figure 1.--An example diagram of an approach for the investigation of intellectual processes common to mental ability tests and learning tasks.

may be possible that different cognitive processes, as measured by complex tests of induction, relate differentially to performance in different treatment conditions. This type of knowledge would increase understanding concerning the relationship of induction to performance on concept-learning tasks.

A preliminary study was undertaken to investigate the concept that known ability tests are composed of specifiable cognitive processes. The general approach was to examine the known tests that define a specific ability, with respect to the cognitive processes the subject must perform in order to attain an adequate score on that ability. In a study reported in Costello and Dunham (1971), such an analysis of the induction factor was undertaken.

The French Kit of Reference Tests for Cognitive Factors defines induction primarily by two tests: Locations Test and Letter Sets. With respect to the cognitive processes that the subject must perform, preliminary analyses of these two tests revealed three hypothesized cognitive processes: hypothesis generation, evaluation, and memory for generated hypotheses. Two measures for each of the processes were constructed.

The subjects were 75 undergraduates from introductory educational psychology classes at The University of Texas at Austin. The battery of cognitive tests was selected from the Kit of Reference Tests for Cognitive Factors and from Guilford's Structure-of-Intellect Model (Guilford, 1967). In addition. all subjects were administered two tests for each of the hypothesized cognitive processes: hypothesis generation, evaluation, and memory.

The factor analysis revealed three factors which coincided with the hypothesized cognitive processes of evaluation, hypothesis generation, and memory. The high multiple $\underline{R}$'s for the induction tests, using only the factor scores as predictors, seem to imply that the hypothesized cognitive processes may, in fact, adequately describe the processes needed to account for performance on tests such as Letter Sets and Locations. Measures for mental abilities, such as General Reasoning, Associative Memory, and Flexibility of Closure, were included to determine whether measures of cognitive processes would have a relationship with tests other than those of induction. The multiple $\underline{R}$'s for these measures, although generally not as high as those for induction, suggest that other mental ability tests may also have specifiable component processes.

The two tests from Guilford's Structure-of-Intellect Model are tests of cognition for semantic classes and of divergent production of semantic classes. The multiple $\underline{R}$'s for these tests also imply that individual variation on ability tests may be, in part, a function of individual differences, with respect to some specifiable cognitive processes.

A preliminary investigation of this type is not offered as conclusive evidence that abilities are composed of specifiable cognitive processes. It does, however, suggest that across a diverse range of mental abilities, there is a substantial relationship between abilities and measures of cognitive processes. This then implies that, in studying the relationship between abilities and performance on concept-learning tasks, it may be unnecessary to administer large batteries of ability tests. Rather than behavior being described by a battery of ability tests, it may be adequately described by a few measures of cognitive processes. If this is the case, then abilities could be understood in terms of their component cognitive processes, and theories of concept learning could be formulated describing performance as a function of several cognitive processes. This would then allow the investigation of individual difference parameters within a concept-learning model.

In most studies involving concept-learning tasks, the dimensions of the task are specified to the subject. This has the effect of limiting the number of possible hypotheses with which subjects must deal. If such studies are concerned with the processes relevant to the induction of a class concept, then limiting the number of possible hypotheses lessens the role of processes necessary to the generation of hypotheses. In the study reported by Dunham and Costello (1971), the concept-learning task was constructed such that the dimensions were not previously specified and therefore would not restrict the number of possible hypotheses.

These concept-learning problems can be solved by forming hypotheses with respect to other instances of the concept. The subjects first must form and then must use these hypotheses to attain the correct concept. It was hypothesized that different experimental treatment manipulations, such as the availability of possible hypotheses, would alter the relationship between performance on the concept-learning problems and the cognitive process measures.

Measures for the three hypothesized cognitive abilities, along with eight concept problems, were administered to 118 subjects who were students at The University of Texas at Austin. The subjects were randomly assigned to two groups (1) Relevant hypotheses were provided for the first four concept problems (hypothesis-supplied), and (2) no such provision was made (no-hypothesis supplied). Instructing a group of subjects to use hypotheses relevant to attaining solutions in a series of concept problems did contribute significantly to their mean performance when compared to a group that was not given the hypotheses.

It was hypothesized that the availability of possible hypotheses should both minimize the role of the cognitive ability of hypothesis generation and should place a greater emphasis on the role of evaluation of the given hypothesis. In the no-hypothesis supplied condition, the subjects must generate their own hypotheses about the nature of the solution, thereby placing a greater importance on the cognitive ability of hypothesis generation.

The results suggest that subjects attaining solution in one of the two conditions had different cognitive ability profiles. This was supported by the discriminant analysis of subjects who attained solution in both conditions. Therefore, it seems apparent that the manipulation of availability of hypotheses resulted in a change in the nature of the information processing which occurred in the two groups. This change then became manifest in the relationships of performance to process measures.

The advantage of using constructs, such as hypothesis generation and evaluation, as cognitive abilities is that they allow the researcher better understanding concerning which cognitive processes are involved in well-established measures of abilities, such as induction. This, in turn, provides a vehicle for interpreting the relationships between known cognitive abilities and performance on learning tasks. Previous studies of this type have shown induction to emerge as a general factor and probably to be more indicative of some overall level of performance. Also, in most studies of abilities and their relationships to learning, induction has been shown to have a strong relationship to different treatment groups within the same experiment. Unfortunately, this has forced researchers to pay attention to abilities that exhibit weaker relationships to learning when these relationships vary between treatment groups.

Toward a Hypothesis Construction Model of Concept Identification

Most well-developed theories of concept learning have dealt with the simplest of concept problems. In particular, the mathematical theories have primarily been concerned with the two-category unidimensional problems. These problems are quite easy for human subjects, thus placing little demand on intellectual abilities. Since the theories have been quite successful with simple problems, an effort was undertaken to expand these theories in order to describe the performance in more complex concept-learning situations. In these situations, it was felt that there would be more demand on the cognitive apparatus of the subject, and individual differences would have to be taken into consideration. The assumption here is that as theories of simple learning are expanded to more complex problems, learning must be expressed as a function of individual difference parameters representing human abilities.

The first effort in this direction concerned a definition for which type of theory was more relevant to describing more complex concept learning. Information-processing theories of problem solving may be divided into two classes. (1) The first assumes that subjects enumerate all possible solutions and then use a set of procedures to find the correct solution. (2) The second assumes that subjects employ a set of processes (heuristics) to construct possible solutions to the problem by basing their solutions on the kind and amount of information available at that time. The subject then evaluates the adequacy of the tentative solutions.

Polson and Dunham (1970) classified theories of concept learning along these lines into hypothesis-sampling models and hypothesis-construction models. They demonstrated that, as the number of values on a dimension increases, a hypothesis construction theory is necessary to explain the data.

The next effort related to theories of concept learning in this vein concerned the development of a hypothesis construction (HC) theory. A tentative version of an HC model, developed by Reeve, Polson, and Dunham (1970), makes the following assumptions about the learning of unidimensional multiple-category concept problems:

(1) *On the initial trial, and on any other trial where he resamples, the subject selects from the set of all dimensions, a subset of dimensions to which he attends.* As in the Trabasso and Bower (1968) theory, the selection mechanism is assumed to be a random-sampling process in which the probability of sampling any dimension is a function of the salience of the dimension.

(2) *All values of the sampled dimension are summed not to be conditioned immediately following sampling.* On the trial in which sampling occurred, or on any other trial, the feedback is conditioned with probability θ to all current unconditioned values of the attended-to dimensions.

Trabasso and Bower (1968, Chap. 2) assume that the subject alternates between a search mode and a test mode of operation. In the search model, the subject selects a set of hypotheses consistent with current feedback. The subject then shifts to a test mode for the next stimulus in the series. In the multiple-category problem, this distinction cannot be sharply defined. Rather than sampling hypotheses, the subject samples dimensions and then constructs hypotheses consistent with the feedback given with each instance. He may have the opportunity to test the partial hypothesis prior to completely specifying it.

On any trial, the subject is confronted with a complex and possibly conflicting stimulus pattern to which to respond. The value of each of the sampled dimensions may be conditioned to any of the n responses, or it may be unconditioned. Consistent with Trabasso and Bower (1968), the response rule to be assumed is as follows: When presented with a situation where all values are conditioned to a common response, the subject makes the response. In any other situation, one value is picked at random, and the subject makes the response associated with the sampled value. If that value is unconditioned, the subject guesses with each of the responses having equal probability of occurring.

The final process is for eliminating dimensions from the focus sample. Again following Trabasso (1968), it is assumed that an error of commission leads the subject to resample. When the subject is responding for a reason and is correct, those dimensions whose values were associated with incorrect responses are eliminated from the sample. Trabasso and Bower did not have to deal with the third possible outcome, where the subject guesses. It is assumed that regardless of whether or not he guesses correctly, the action is the same as when the subject is correct for a reason. Those dimensions leading to an error of commission are eliminated from the sample.

The HC model with the attentional and focusing assumptions can be summarized briefly as follows: (1) The subjects current state is characterized by his current sample and the response (if any) associated to each value of each dimension of his sample. (2) The subject changes state by associating responses to values previously unconditioned, eliminating dimensions from the sample, or resampling. (3) When one or more unconditioned values are presented with feedback, the feedback is conditioned to these values with probability θ. (4) When the subject makes an error of commission, he resamples. A sample of dimensions is chosen, with replacement, from the set of all dimensions. The probability of choosing any dimension is a function of its salience. (5) When the subject makes a correct response or is guessing, dimensions having values conditioned to an incorrect response are dropped from the sample. (6) On any trial, the probability of each response is proportional to the number of values conditioned to that response. Any unconditioned value is assumed to contribute equally to the probability of each n responses.

Preliminary testing of this model appears in Reeve (1971). A refined and more explicit version of the above summary may be found in this report.

(3) *A third effort concerned transfer within this theoretical frame.* The models discussed are information-processing models. Instruction effects are of central importance for information processing models of transfer. Polson and Dunham (1970) investigated the effects of instructions within a variety of concept-learning transfer paradigms. They concluded that transfer performance is a function of instructions at the transfer point and of the instructions prior to original learning, as well as the type of transfer paradigm. They conclude that information processing models assume that transfer performance is determined by the type of information processing strategies that the subject employs during the initial trials of the transfer task. The strategies that the subject uses are determined by the nature of the transition (i.e., the type of transfer paradigm) and the information that the subject has about the relationship between the two problems. Instructions can modify the utilization of these strategies, and thus instructions and transfer paradigm may be equally powerful determiners of transfer performance. This claim follows from any general information processing theory of problem solving. These theories assume that the subject uses some subset of a larger collection of information processing strategies to find a solution to a problem. Furthermore, we cannot assume that the subject will use a fixed set of strategies to solve a given class of problems.

The effects of nonspecific transfer, instructions, and pretraining imply that these variables cause qualitative differences in performance and that the subject changes the set of currently active strategies as a function of experience and/or additional information about the task.

Extensions of the Methodology

A study was undertaken (Hollen, 1970) to investigate the roles of selected cognitive abilities in obtaining information from passages of prose materials when the presence and position of adjunct questions were varied. Predictions were made that the associative memory ability and a postulated chunking memory ability would be related to task performance as measured by posttests of retention of information.

Ability measures, task materials, and a posttest of retention were administered to 136 subjects from introductory classes at Sul Ross University under three treatment conditions: (1) an adjunct question preceding each passage, (2) an adjunct question following each passage, and (3) no adjunct question. After random assignment to treatment groups, the subjects were further divided into groups for whom English was a primary language and for whom it was an acquired language.

Results indicated that only the associative memory ability was needed for task performance. A reduction in need for the ability in both tasks occurred when questions followed passages; no reduction occurred when questions preceded passages.

Disordinal interactions of treatments with associative memory observed in this study imply that in the absence of adjunct questions, subjects adopted strategies of information processing maximizing the need for associative memory, but they changed to strategies minimizing this need when questions followed passages. The change in strategies was more appropriate to task performance for subjects low in the ability, less appropriate for subjects high in the ability.

Questions were raised as to the generality of findings from previous studies concerning the facilitative effects of adjunct questions. Performance of subjects high in associative memory was actually impaired by the use of adjunct questions. A basis for future investigations was provided by data from subjects for whom English was an acquired language. Results suggest the possibility that such subjects adopt information-processing strategies that differ from those adopted by subjects for whom English is a primary language.

During the term of this program of research, a number of studies were designed to assess the relationship between cognitive abilities and performance on various learning tasks. It was repeatedly shown that observed relationships between cognitive abilities and performance vary under different experimental treatments. Another study (Meyers & Dunham, 1971) was undertaken to attempt to broaden the ability by treatment interaction paradigm through the examination of anxiety and task involvement as they contribute to the relationship between abilities and performance.

There were four experimental conditions, defined by all combinations of two types of concept transfer conditions, and two types of ego-involvement instructions (high ego-involvement and low ego-involvement). All subjects received two consecutive unidimensional, four-category concept problems. The second problem served as the transfer problem. The two transfer conditions were extradimensional shifts which differed as to whether the dimensions and values of the transfer problem were the same (EDS) as those in the original learning problem or if they consisted of new (EDN) dimensions and values. Consequently, it was expected that, because of negative transfer, the EDS problem would involve competing responses, and thus anxiety would have a relatively debilitating effect.

The subjects were 188 introductory educational psychology students at The University of Texas at Austin. They were first administered a battery of ability tests from the French Kit of Reference Tests.

Change scores (i.e., number of trials to criterion on original learning problems; number of trials to criterion on transfer learning problems) were employed as the dependent measure to assess transfer. An analysis of variance was used to assess the effects of transfer and involvement conditions. The major findings for this analysis were that the EDS shift was significantly more difficult than the EDN shift and that there was no significant difference in the performance of subjects between high and low involvement instructions.

A regression analysis was completed in order to assess the interactive effects of anxiety and abilities on performance. Although it was reported above that there were no significant differences in performance based on "involvement instructions," the significant interactions with anxiety and ability variables occurred only with low involvement. Under this condition, there was a significant interaction between anxiety and memory span for both the EDS and EDN condition. Moreover, the relationship between anxiety and performance was relatively debilitating in the EDS when compared to the EDN problem.

The major finding of this study was the interaction between anxiety and memory span, which occurred despite the lack of correlation between these two variables. This finding implies that anxiety inhibits the utilization of the memory-span attitude, and it provides support for the notion that not only treatment conditions but also personality and motivational factors should be considered within the aptitude by treatment interaction paradigm.

SECTION IV

EVALUATION AND CONCLUSIONS

The stragegy on which this project was based was reviewed in the first section of this report. It attempts to develop a continuum between research, theory, and methodology in the psychological investigation of complex human learning and applied curriculum development, primarily for CAI. This continuum can be represented as follows:

Body of Psychological Research, Methodology, & Theory (Human Learning) ↔ Concept Learning Laboratory Tasks ↔ Xenograde CAI Program ↔ Design Model ↔ Applied CAI Curriculum Development

Substantive matters within the three middle categories have been reviewed within the body of this report. The purpose of the present section is to evaluate the extent to which the transitions between the areas represented above occurred. These transitions are represented by arrows.

Between the body of psychological knowledge in concept learning and our laboratory studies, the distance is short, and the integration thorough. Guided by Propositions 1, 2, and 3, discussed earlier in Section III, we have produced steady, and hopefully useful, increments in empirical data, methodology, and theory. Most contributions have been dependent on the detailed information-processing analysis of concept-learning tasks, which is the hallmark of our methodology. This provides a rational approach to the identification and interpretation of relevant aptitudes and their interactions. It also provides a route to the construction of powerful and useful hypothetical constructs. The combination of treatment manipulation and aptitude covariation is a useful methodology for establishing construct validity. It is far stronger than procedures which limit themselves to the aptitude or experimental domain exclusively.

In our estimation, the most important methodological and conceptual contribution of this project is the "process measure" approach described in Section III. Not only does this provide a methodology for aptitude x treatment studies which promises to be clearer conceptually, but it may prove to be an important step toward the formulation and evaluation of hypothesis-construction theories of complex human learning--theories which incorporate ability parameters representative of constructs having a separate source of empirical construct validation.

While important initial steps toward this goal were achieved during the course of this brief project, considerable work remains to be done before the "process measure" approach is adequately evaluated. The actual extent of its importance must be established by considerably more research and more theoretical development.

The transition between the laboratory research and the Xenograde research fell short of expectations at the operational level. It cannot be said that cross-validation of results between the two classes of learning tasks occurred in any important way. This was true even in the simple case of the role of memory ability as influenced by the availability of previous examples.

The first problem obstructing operational cross-validation lies in the fact, observed by Glaser (1968), that laboratory studies of concept learning almost exlusively use an inductive approach. Glaser notes: "It seems contradictory that in psychological experiments we have been studying just the types of concepts that might best be taught by presenting the rule first."

In addition to the inductive emphasis in psychological research, the sequences of examples are usually random or, at best, arbitrary. In Xenograde, the most instructionally-effective treatment used an explicit rule-example presentation to establish the various relational concepts which comprise the Xenograde hierarchy. Sequence was shown to be a powerful influence on performance. This method was far more efficient and sometimes superior in terms of posttest, retention, and transfer than the inductive (discovery) approach using examples only. In this efficient treatment, the relationship of aptitudes to performance was greatly reduced or eliminated altogether.

The factors of rule instruction and sequence were not entirely ignored in our laboratory research. Decision rule instruction played an important role in the studies discussed in Section III. The relationship between sequence effects and performance, when strategies using different decision rules are considered, was also studied by Blaine and Dunham (1970). However, it cannot be said that the most straightfoward and efficient instructional design was ever used in these tasks.

In one sense, the lack of clear cross-validation between laboratory and Xenograde aptitude x treatment studies can be viewed as a "success story." From the instruction design point of view, we have learned how to reduce or to remove the constraint on learning associated with low scores on certain aptitude tests. This is done in an efficient manner through the use of rule-example sequences ordered in accord with a cumulative hierarchy. If laboratory concept-learning studies would use these techniques, it would have at least two noticeable effects. First, a certain body of research and theory would be shown to be irrelevant to human instruction. It would prove to be an artifact of keeping subjects in the dark. Second, a relatively untilled area in human concept learning would begin to be exploited. Sources of variance, remaining after complete and thorough instructional design is applied, may prove to be as interesting or more interesting than the dependent variables now studied in concept learning. Conversely, the theory behind the effectiveness of these instructional manipulations could be developed. Such research would lead toward a psychology of instruction as contrasted to a psychology of learning.

An evaluation of this project does not reveal that operational transfer of results between tightly controlled laboratory research and research using complex instructional tasks cannot be accomplished--only that it had not been accomplished in a convincing manner by the end of this particular contract. On the other hand, important transfer at a conceptual and methodological level did occur. Information-processing analyses were applied on both Xenograde and concept problems. Learning Xenograde can be characterized as the acquisition of a complex, conditional, relational concept. This concept can be represented as a set of 10 decision rules which must be applied in a certain sequence. These rules and their sequence were obtained by a new task-analysis procedure which is generalizable. The information-processing task-analysis procedure developed in the Xenograde studies may prove to be a worthwhile contribution to the learning hierarchy literature.

An attempt was made to develop new "process measure" tests in the Xenograde studies. However, the new Xenograde tests did not seem to measure true processes as defined in Section III. Possible exceptions are the "chunking memory" process tests developed by Hollen (1970) (which were not a notable success in achieving construct validity) and perhaps Merrill's (1970) memory test. Merrill's new tests for reasoning seemed to be parallel forms of traditional Induction and Reasoning tests expressed in the stimulus materials and, to some extent, the complex processes implied by Xenograde rules. The simpler processes of hypothesis generation and evaluation developed by Costello and Dunham (1971) are more representative of the meaning implied by the term "process measures," as used here.

In moving now to a consideration of the transfer of Xenograde results to the instructional design model, it must be said that the initial model for use of aptitude x treatment results did not transfer. As discussed in Section II, the notion of locating disordinal interactives and using test scores to branch to two or more alternate macro-treatments was not seen as promising. Our data do not provide a justification for generalization of this conclusion beyond the use of short-term concept, rule-learning tasks, and cognitive aptitudes, although this conclusion may be more general.

Again, at the methodological and conceptual level, important transfer did occur between the Xenograde studies and the instructional designer's needs. The information-processing task-analysis procedure is now a part of applied curriculum development efforts in this laboratory. The knowledge that aptitude constraints can be removed or reduced by clear rule-example presentation and by the use of objectives has been translated into some CAI computer programs. Techniques of learner control over sequence and display variables have been incorporated into some CAI programs and are being evaluated (Judd, Bunderson, & Bessent, 1970).

The instructional design model has evolved substantially during the course of this research program. There is a good match between the design products and possibilities for experimental manipulation in the Xenograde programs and the categories of the instructional design model. On the negative side, the imaginary nature of Xenograde has limited the generality of results obtained through use of this task. Some students are not interested in learning an imaginary science. However, since some students are not interested in learning anything difficult, we are not sure how far our results have been biased.

Originally, the imaginary character of Xenograde was felt to be useful experimentally since it provided control over prior learning. As so often proves to be the case in research, its greatest value was not related to this supposed purity from prior knowledge. Prior experience with quantitative rules, numerical tables, and "scientific thinking" was not controlled by the unfamiliar content. The great utility of the imaginary task proved to be in freeing the experimenter-instructional designers from concern about related scholarship, teaching traditions, etc. It thus became possible to concentrate on questions of task structure, sequence, and display without being constrained by other concerns. When some characteristic of the task hindered experimental objectives or efficient instruction, the laws of the "science" could be changed.

Another advantage of Xenograde was the conscious attempt to link the Xenograde program to the real tactical needs of the instructional designer. This program was designed following the guidelines laid down by the model. It thus underwent extensive revisions on the basis of feedback from students in the early studies.

The importance of revision based on student feedback cannot be overstressed. As discussed in Section II, the gain in instructional effectiveness due to revision may be greater than the gain possible as the result of branching to an alternate treatment based on an aptitude score. The same statement may be made of an instructional decision based on any other proposition.

In evaluating the transfer between the Xenograde studies and the instructional design model, it must be stated that the impact of formative evaluation and revision on the relevance of research had not been fully perceived. If research on complex tasks does take place before these tasks are thoroughly tested and revised, it may be in vain insofar as relevance is concerned. On the other hand, if researchers fully comprehend the decision processes of an instructional designer who is faced with data which indicates the need for revision, they may be able to develop and validate instructional theorems which can guide the revision process.

It was not the purpose of this research to contribute directly to the transfer between the instructional design model and applied curriculum development. In the present project, the instructional design model stands as a representational scheme to describe an "engineering discipline" for education. It is focused primarily at the engineering of high quality CAI programs. In order to complete this discussion, something should nonetheless be said concerning the effectiveness of the model in guiding quality curriculum development. The empirical proof of this particular "pudding" comes through the evaluation of the CAI programs generated by following the model (with a large dash of taste and creativity thrown in to moderate its otherwise mechanical prescriptions). The results are most promising: Among other topics, the model has been successfully applied to freshman mathematics (Judd, Bunderson, & Bessent, 1970), freshman English, computer science (Homeyer, 1970), freshman chemistry, and the Arabic writing system (Abboud, 1970). In the case of the Arabic program, the evaluation results are as much or more a vindication of the instructional design model as of CAI. Abboud's instructional design thoroughly restructures the current pedagogical procedures for the Arabic writing system in a manner only partially dependent on a CAI implementation. An evaluation study has revealed that classroom instruction extending over six weeks, six hours per week, in Arabic can be replaced by from five to ten hours at the CAI terminal. Contrary to classroom instruction, attrition rate is very low or nonexistent. Attitudes are very positive, performance scores are significantly higher than in classroom instruction, and apparent transfer to later classroom work is greater.

In conclusion, this section has attempted to evaluate the feasibility of a strategy which seriously tried to provide a series of links between practical questions of instructional design and a science of human learning. The conclusions of this evaluation can be summarized in terms of two rubrics: operational cross-validation and metaphorical transfer.

At the level of operational cross-validation between laboratory tasks and instructionally-oriented tasks, this strategy did not succeed during the two years allotted to this project. There is no evidence that it cannot succeed, if given more time, given a conscious recognition of the difficulty of the endeavor, and given a recognition of the possibility that the methods, paradigms, and models of psychological research can be modified to be more relevant to instructional theory.

To be more relevant to instruction, the psychological study of concept learning could incorporate the following suggestions:

(1) It should investigate behavior under expository as well as inductive presentations. Complex and cumulative sequences of concepts should be investigated.

(2) It should consider more carefully seemingly microscopic sequence effects between adjacent concept exemplars. Stated alternately, it should investigate the manner of constructing adjacent and near-adjacent examples and non-examples to take advantage of design strategies.

(3) Cognitive aptitude covariables should be incorporated in experimental designs, but as "process measures" rather than strictly in the form of more traditional tests. In computer-based research, aptitudes may be measured on-line and as a subtle part of learning activities themselves. In CAI, aptitude parameters should be related to micro-adaptive mechanisms (i.e., control over sequence parameters or display parameters) rather than as the basis for branching to alternate macro-treatments (alternate programs). Aptitude x aptitude x treatment interactions should be studied as well as the case with single aptitudes.

(4) Research should take into account the payoff from an instructional decision relative to the payoff from revision of the learning task. Whether based on an individual aptitude parameter or an implied group mean difference, an instructional decision may produce a less significant effect than revision. Revision may be less costly than the research, or it may alleviate the need for the decision. Improvement through revision may be due to a series of minor modifications, made at points where feedback from students has revealed deficiencies, or it may be based on a restructuring of an important variable which runs throughout the treatment.

A corollary to this last guideline is that tasks used in human learning research should reach an asymptote in effectiveness produced through formative evaluation and revision before lavishing the money, time, and talent of a research establishment on them.

At the level of metaphorical transfer of the procedures, tactics, and conceptual approaches, the project rates more highly. Some important ideas which reverberated throughout all aspects of the project are the ideas of information-processing task analysis, "process measures" for aptitudes, and aptitudes as parameters having independent construct validity. In addition to these instances of positive transfer, the strategy permitted the identification of exactly where transfer was hindered, due to different emphasis or procedures in laboratory and instructional research.

APPENDIX

APPENDIX

PUBLICATIONS OR PAPERS RESULTING FROM WORK CONDUCTED UNDER ARPA CONTRACT

Technical Reports

Tech 1 Dunham, J. L., & Bunderson, C. V. Effect of decision rule instruction upon the relationship of cognitive abilities to performance in multiple-category concept problems, 1971.

Tech 2 Bunderson, C. V., & Merrill, P. F. The design of an abstract hierarchical learning task for computer-based instructional research, 1971.

Tech 3 Bunderson, C. V., Merrill, P. F., & Olivier, W. P. The interaction of reasoning and memory abilities with rule-example vs. discovery instruction in learning an imaginary science, 1971.

Tech 4 Olivier, W. P. Program sequence by ability interaction in learning a hierarchical task by computer-assisted instruction, 1970.

Tech 5 Merrill, P. F. Interaction of cognitive abilities with availability of behavioral objectives in learning a hierarchical task by computer-assisted instruction, 1971.

Tech 6 Bunderson, C. V., & Hansen, J. B. The interaction of associative memory and general reasoning with availability and complexity of examples in a computer-assisted instruction task, 1971.

Tech 7 Blaine, D. D., & Dunham, J. L. Strategy instruction and type of sequence in concept attainment, 1971.

Tech 8 Overstreet, J. D. The roles of stimulus complexity and information processing rules within two phases of multiple-category attainment, 1971.

Tech 9 Blaine, D. D., & Dunham, J. L. The effect of availability on the relationship of memory abilities to performance in multiple-category concept tasks, 1971.

Tech 10 Dunham, J. L., & Polson, P. G. Theories of unidimensional concept identification, 1971.

Tech 11 Meyers, J., & Dunham, J. L. An investigation of the effects of anxiety, abilities, and task characteristics on concept learning, 1971.

Tech 12 Dunham, J. L., & Blaine, D. D. The relationship of abilities to different stages of concept attainment, 1971.

Tech 13 Dunham, J. L., & Costello, R. J. Intellectual processes in concept learning, 1971.

Tech 14 Polson, P. G., Dunham, J. L., & Reeve, M. B. Effects of instructions on performance in three shift paradigms, 1971.

Technical Memos

Systems Memo 1 Smith, A., Wheaton, M., Gregory, C., & Bunderson, C. V. A Coursewriter II function (fcalc) for the manipulation of numerical and algebraic expressions, 1970.

Systems Memo 2 Wheaton, M., Groom, V., & Bunderson, C. V. Coursewriter II functions for the generation and display of plots and other graphics, 1970.

Articles Published in Journals

Blaine, D. D., & Dunham, J. L. The effect of availability on the relationship of memory abilities to performance in multiple-category concept tasks. *Journal of Educational Psychology*, 1971. (in press)

Dunham, J. L., & Bunderson, C. V. Effect of decision-rule instruction upon the relationship of cognitive abilities to performance in multiple-category concept problems. *Journal of Educational Psychology*, 1969, 60(2), 121, 125.

Articles Published in Formal Proceedings

Bunderson, C. V. Justifying CAI in mainline instruction. In *Proceedings of the Conference on Computers in the Undergraduate Curricula*. Sponsored by the National Science Foundation. Gerard P. Weeg (Conference Organizing Committee Chairman). Iowa City: The University of Iowa, June, 1970.

Bunderson, C. V. Instructional software engineering. In Blum, R. (Ed.). *Proceedings of the Conference on Computers in Undergraduate Science Education.* College Park, Maryland: Commission on College Physics, University of Maryland, 1971. (in press)

Dissertations

Blaine, D. D. Process measures for concept learning. In progress.

Costello, R. J. The role of inductive reasoning processes in concept learning. In progress.

Hollen, T. T. Interaction of individual abilities with the presence and position of adjunct questions in learning from prose materials, 1970.

Merrill, P. F. Interaction of cognitive abilities with availability of behavioral objectives in learning a hierarchical task by computer-assisted instruction, 1970.

Meyers, J. An investigation of the effects of anxiety, abilities, and task characteristics on concept learning, 1971.

Olivier, W. P. Program sequence by ability interaction in learning a hierarchical task by computer-assisted instruction, 1970.

Overstreet, J. D. The roles of stimulus complexity and information processing rules within two phases of multiple-category concept attainment, 1970.

Reeve, M. B. A theory of multiple-category concept identification. In progress.

Papers Read at Professional Meetings

Blaine, D. D., & Dunham, J. L. The effect of available instances on the relationship of memory abilities to performance in a concept learning task. Paper presented at the annual meeting of the American Educational Research Association, Los Angeles, February, 1969.

Blaine, D. D., & Dunham, J. L. Strategy instruction and type of sequence in concept attainment. Paper presented at the annual meeting of the American Educational Research Association, Minneapolis, March, 1970.

Bunderson, C. V. Ability by treatment interactions in designing instruction for a hierarchical learning task. Paper presented at the annual meeting of the American Educational Research Association, Los Angeles, February, 1969.

Bunderson, C. V. Aptitude by treatment interactions: of what use to the instructional designer? Paper presented at the annual meeting of the American Psychological Association, Washington, D.C., September, 1969.

Bunderson, C. V. Aptitude by treatment interactions: old problems, new approaches, recent data. Discussion group chaired by Robert Glaser at the annual meeting of the American Psychological Association, Miami, September, 1970.

Costello, R. J., & Dunham, J. L. Inductive Reasoning processes in concept learning. Paper presented at the annual meeting of the American Educational Research Association, New York City, February, 1971.

Dunham, J. L. Investigations of the role of intellectual abilities in concept learning. Paper presented at the annual meeting of the American Educational Research Association, Los Angeles, February, 1969.

Hansen, J. B., & Bunderson, C. V. The interaction of associative memory and general reasoning with ability and complexity of examples in a computer-assisted instruction task. Paper presented at the annual meeting of the American Educational Research Association, New York City, February, 1971.

Merrill, P. F. Designing and developing an imaginary science program in instructional design and theory. Paper presented at the meeting of the Association for the Development of Instructional Systems, Los Angeles, February, 1969.

Meyers, J., & Dunham, J. L. An investigation of the effects of anxiety, abilities and task characteristics on concept learning. Paper presented at the annual meeting of the American Educational Research Association, New York City, February, 1971.

Overstreet, J. D., & Dunham, J. L. Stimulus complexity and information processing rules in multiple-category concept identification. Paper presented at the annual meeting of the Southwestern Psychological Association, St. Louis, April, 1970.

Polson, P. G., & Dunham, J. L. A comparison of two types of theories of multiple-category concept identification. Paper presented at the annual meeting of the Mathematical Psychologists Conference, Indiana University, Bloomington, April, 1970.

Polson, P. G., Dunham, J. L., & Reeve, M. B. Effects of instructions on performance in three concept shift paradigms. Paper presented at the annual meeting of the Midwestern Psychological Association, Cincinnati, 1970.

Wheaton, M. Use and design of the plot function. Paper presented at the meeting of the Association for the Development of Instructional Systems, New York City, March, 1970.

Table 1

Summary of Research Conducted Wholly or Partially Under ARPA Contract

Study or Activity	Code*	Products Completed
I. Studies Related to Use of Xenograde Program		
A. Discovery vs. Expository Treatments		
--and Simulation	FP	Discussed in Bunderson (1971)
--General Reasoning, Memory, Induction	T3	Bunderson, Merrill, & Olivier (1971)
--Reasoning and Performance Objectives	Dis, T5	Merrill (1970) Merrill (1970)
--Memory and Availability	T6, PS	Bunderson & Hansen (1971) Hansen. & Bunderson (1971)
B. Sequence & Learner Control	Dis, T4	Olivier (1970) Olivier (1971)
II. Instructional Design and CAI		
A. Instructional Design Implications		
--Design and Documentation of Xenograde Program	PS T2	Merrill (1969) Bunderson & Merrill (1971)
--Aptitude X Treatment Interactions and Instructional Design	PS PS	Bunderson (AERA, 1969) Bunderson (APA, 1969; 1970)
--Instructional Design Model	FP	Bunderson (1970a, 1970b)
--Algorithmic Analysis for Learning Hierarchies		Merrill (1971)
B. Program Documentation		
--Mathematical Response Analysis Function	TM1	Smith et al. (1970)
--Plot Functions	TM2, PS	Wheaton et al. (1970) Wheaton (ADIS, 1970)
III. Studies Employing Laboratory Tasks		
A. Analysis of Learning Stages and Decision Rules		
--Decision Rules & Learning Stages	PS, Dis, T8	Overstreet & Dunham (SWPA, 1970) Overstreet (1970) Overstreet (1971)

Table 1 (continued)

Study or Activity	Code	Products Completed
III. B. Decision Rules and Concept Learning Identification		
--Decision Rule Instruction and Aptitudes	T1, JA	Dunham & Bunderson (J.Ed.P., 1969)
--Decision Rules, Learning Stages & Aptitudes	PS, T12	Dunham (AERA, 1969) Dunham & Blaine (1971)
--Sequence Effects & Decision Rules	PS, T7	Blaine & Dunham (AERA, 1970) Blaine & Dunham (1971)
C. Availability of Instances & Memory	PS, JA, T9	Blaine & Dunham (AERA, 1969) Blaine & Dunham (J.Ed.P., 1971) Blaine & Dunham (1971)
D. Process Measures for Aptitude & Learning		
--Relationship of Conceptual Task, Test, & Process Measures	Dis	Blaine (1971)
--Intellectual Processes in Inductive Reasoning & Concept Learning	PS	Costello & Dunham (AERA, 1971)
--Intellectual Processes in Concept Learning	T13, Dis	Dunham & Costello (1971) Costello (1971)
E. Toward A Hypothesis Construction Model of Concept Identification		
--Comparison of Two Types of Theory	PS, T10	Polson & Dunham (MPC, 1970) Dunham & Polson (1971)
--Instructions & Transfer in Concept Shift	PS, T14	Polson, Dunham, & Reeve (MPA, 1970) Polson, Dunham, & Reeve (1971)
--Theory of Multiple-Category Concept Identification	Dis	Reeve (1971)
F. Related Research		
--Adjunct Questions & Memory	Dis	Hollen (1970)
--Anxiety & Aptitude Interaction	PS, T11, Dis	Meyers & Dunham (AERA, 1971) Meyers (1971) Meyers (1971)

*Code Abbreviations:
Tn = Technical Report Number
TM = Technical Memo
Dis = Dissertation
JA = Journal Article
J.Ed.P. = Journal of Educational Psychology
FP = Articles in Formal Proceedings
PS = Paper Presented at Meeting of Professional Society

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